Performance Metrics for Small-Signal Stability Assessment of DC-Distributed Power-System-Architecture Comparisons

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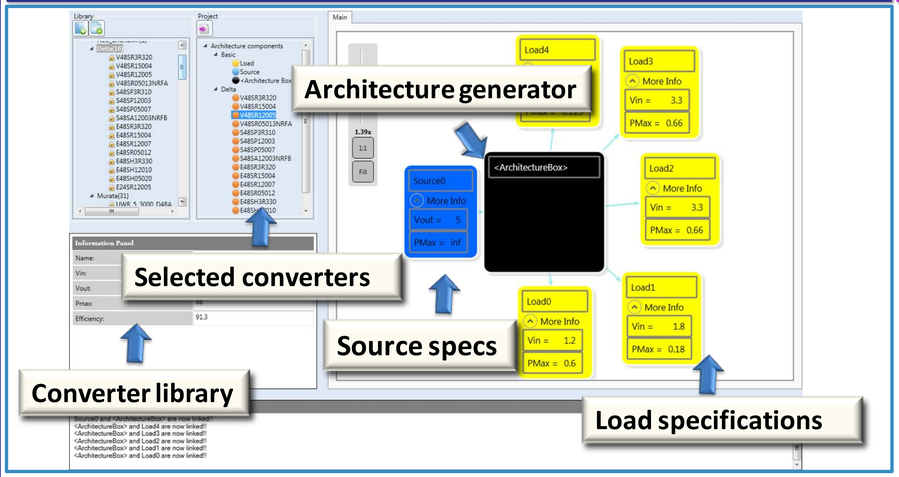
1. ARCHITECTURE OPTIMIZATION TOOL
User interface

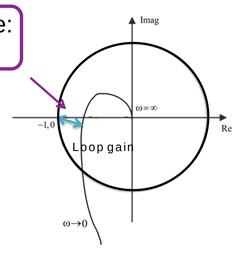


2. STABILITY MARGINS
How close stable system is to instability

Maximum peak criteria MPC

- Prediction of robust stability
- Based on min. distance between -1 and L

Min. distance: $1/S_{max}$



Sensitivity function

$$S = \frac{1}{1+L}$$

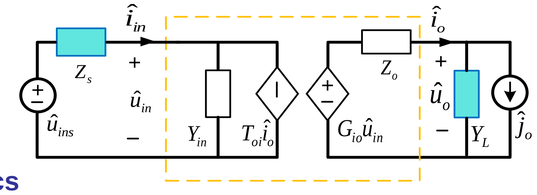
- Both margins:

$$GM \geq \frac{1}{1-1/|S_{max}|} \qquad PM \geq 2\arcsin\left(\frac{1}{2|S_{max}|}\right)$$

➡ Typically $S_{max} < 2$

Converter model

$$\hat{i}_{in} = Y_{in}\hat{u}_{in} + T_{oi}\hat{i}_o$$
$$\hat{u}_o = G_{io}\hat{u}_{in} - Z_o\hat{i}_o$$

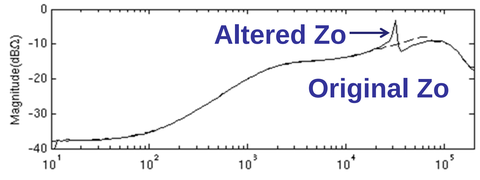


Source-affected dynamics

$$\hat{i}_{in} = S \cdot Y_{in} \cdot \hat{u}_{ins} + S \cdot T_{oi} \cdot \hat{i}_o$$
$$\hat{u}_o = S \cdot G_{io} \cdot \hat{u}_{ins} - S \cdot (1 + Z_s Y_{in-sco}) Z_o \cdot \hat{i}_o$$

$$S = \frac{1}{1+ML}$$

- Altered converter dynamics due to large peak in the sensitivity function



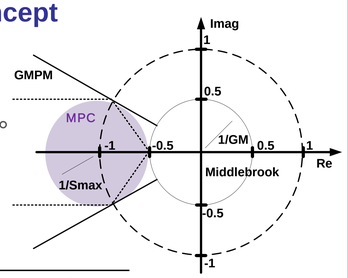
3. STABILITY INDEX
Overall system stability

Application of MPC concept

- Smax = 2 provides margins of

GM ≥ 6dB and PM ≥ 29°

- Combined Smax of each interface

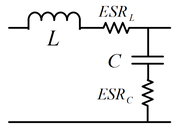


$$G.M. = \sqrt[n]{S_{max1} S_{max2} \cdots S_{maxn}}$$

➡ Best system in terms of robustness minimizes stability index

➡ Detection of the weakest interface H_∞

Input filter



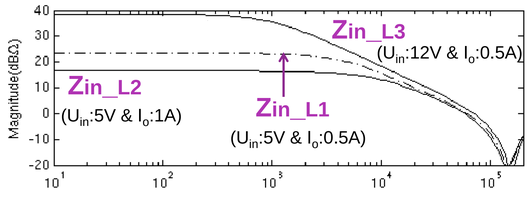
- **F1** (L: 200µH, ESRL: 100mΩ, C: 260µF, ESRc: 100mΩ)
- **F2** (L: 260µH, ESRL: 160mΩ, C: 260µF, ESRc: 100mΩ)
- **F3** (L: 120µH, ESRL: 160mΩ, C: 300µF, ESRc: 100mΩ)

Utilized commercial converters

- Texas Instruments **M2** (Uin: 9-38V Uo: 5V Pmax: 7.5W)
- Traco Power **M3** (Uin: 4.8-36V Uo: 3.3V Pmax: 3.3W)
- National Semic. **M4** (Uin: 3.3-5.5V Uo: 3.3V Pmax: 9.9W)

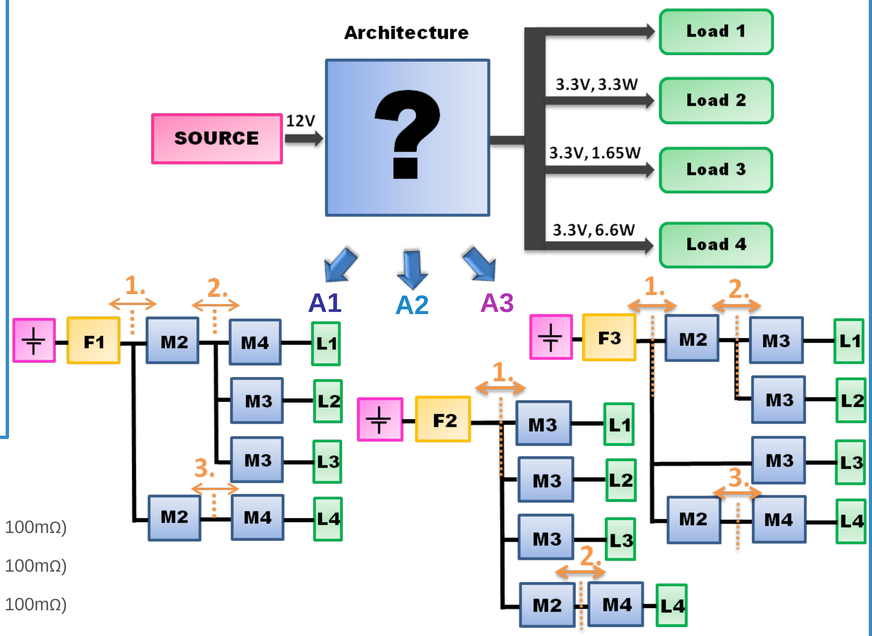
Converter characterization

- Measured Zin of M3 for architecture **A3**



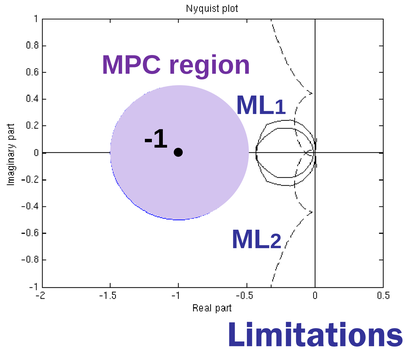
4. ARCHITECTURE COMPARISON
Experimental validation

Static system specifications

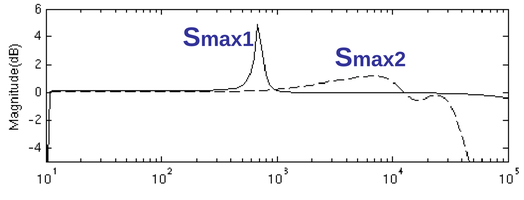


Stability margins for A1 architecture

- Computed minor-loop gains



- Computed Smax values for interfaces 1 and 2



Obtained stability indexes

Interface	A1	A2	A3
1. S_{max1}	1.75	1.66	1.2
2. S_{max2}	1.14	1.16	1.11
3. S_{max3}	1.16	-	1.16
G.M.	1.32	1.39	1.16
H_∞	1.75	1.66	1.2

Limitations of the proposed method:

- Not sufficient condition, but **necessary** ➡ Time-domain simulations for large signal stability
- Linear analysis ➡ Operation-point dependent

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